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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Stress relaxation of seven high-copper dental amalgam alloys was studied over the temperature range of 0 to 55C. At each test temperature the alloy containing the most copper (30 percent) exhibited the lowest rate and lowest magnitude of stress loss.

Stress losses and relaxation rates of all materials increased with temperature. However, patterns of stress decay could be correlated with neither the compositional nor the structural characteristics of the individual alloys.

Stress relaxation behavior may be an indicator of the relative performance capabilities of high-copper amalgams.
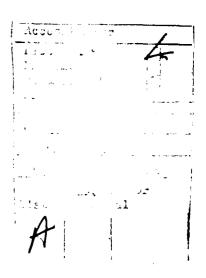
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VISCOELASTIC BEHAVIOR OF HIGH-COPPER DENTAL AMALGAM ALLOYS

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Commercial materials and equipment are identified in this report to specify the

experimental procedure. Such identification does not imply official recommendation

or endorsement or that the equipment and materials are necessarily the best available

for the purpose.

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Since the late 1960's interest in the viscoelastic behavior of hardened dental amalgam has grown markedly. Accordingly, a number of investigators[1-3] have demonstrated the usefulness of laboratory creep data in estimating the clinical performance capabilities of various dental alloys.

In addition to steady state creep, a progressive increase in deformation under constant load, amalgam alloys exhibit other time-dependent characteristics. Once such characteristic is stress relaxation,[4,5] a gradual decrease in stress under constant strain.

Short term stress relaxation behavior of two lathe cut alloys, a spherical alloy of conventional composition, and a material which contained a silver-copper dispersant was examined in a previous study.[5] Comparatively, stress losses and rates of stress decay for the lathe cut alloys were significantly higher than those of the other two materials. The findings suggested that particle morphology and composition affect the stress relaxation of dental amalgam.

The present investigation was conducted to study the stress relaxation behavior of additional relatively new high-copper amalgam alloys (copper content >6 percent).

Materials and Methods

Test materials included two spherical ternary alloys (A,* copper 30% and B,* copper 12%), a spheroidal ternary alloy (C,# copper 13%), a spheroidal quaternary alloy (D,§ copper 13% and Indium 5%), two products formulated from mixtures of fine cut filings of conventional composition and copper-containing

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spherical particles (E,[¶] copper 9% and F,[Ω] copper 12%) and an alloy composed of an admixture of rounded particles and spheres (G,[Π] copper 21%).

Amalgamates of all materials were made with the use of a mechanical device.[**] Mercury-alloy portions and trituration times are given in the appendix.

The amalgams were condensed in 4 mm X 8 mm-steel molds by the all-mechanical procedure prescribed by American Dental Association Specification No. 1.[6] The specimens were aged for seven days at 37C and 100 percent relative humidity. The ends of the hardened test pieces were ground flat and perpendicular to their axes.

The test procedure was designed to measure stress relaxation of the alloys at nominal temperatures of 0, 10, 20, 30, 37, 42, 48 and 55C. The amalgam cylinders were immersed in a water bath and conditioned for 15 minutes at the desired test temperature. Six specimen-lots of each alloy were tested within the bath at each of the aforementioned temperatures. Each cylinder was compressed axially on a constant strain-rate testing machine.[++] Crosshead speed of the machine was 0.02 inch/min. When a stress (S_o) of 28 MN/m^2 was reached, descent of the crosshead was stopped. Relaxation of the loaded specimens yielded a measurable stress loss (D_t) with no change

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¶ Optaloy II, L. D. Caulk Co., Milford, DE 19963.

Ω Dispersalloy, Johnson & Johnson, East Windsor, NJ 08520.

Π Cupralloy, Weber Consumable Products, Mount Vernon, NY 10533.

** Wig-L-Bug, Crescent Dental Mfg. Co., Lyons, IL 60534.

++ Instron Universal Testing Machine, Instron Corp., Canton, MA 02021.

in strain. Stress relaxation (D_t) was measured at 6-second intervals over

a period of 60 seconds. To compensate for the inherent relaxation of the

testing machine, a 4 mm X 8 mm cylinder of stainless steel was subjected to

the compression procedure before and after the testing of three amalgam

specimens. The resulting system relaxation pattern was used in adjusting

the experimental data. An illustration of the compression-relaxation se-

quency can be found in an earlier report.[5]

Results

Fractional stress-loss (D_t/S_o) patterns of the high copper alloys at

one test temperature (34C) are shown in Figure 1. Fractional stress losses

did not increase linearly over the 60-second period of observation. However,

all curves representing the behavior of the alloys at each of the eight ex-

perimental temperatures become linear when plotted against ln (time + 1).

Relaxation rates with reference to ln (time +1) were defined by the slopes

of these lines. Relative relaxation rates for the alloys over the entire ex-

perimental temperature range are shown in Figure 2. Relaxation rates for

materials A, D and E varied exponentially with temperature. Curves depicting

the relative relaxation rates of the other alloys were complex. Relaxation

rates of alloys B, C, F and G increased exponentially with temperatures

ranging from 0 to 48C. The relaxation rates of the latter four materials

appeared to be constant between 48 and 55C.

Mean values for total stress loss at 60 seconds ($D_t/S_o/60$) are given

in Table 1. Over the 0 to 55C temperature range, alloy E exhibited the

greatest increase in stress decay (10 to 56 percent); alloy A showed the

least increase (5 to 21 percent).

Discussion

From the available data, the extent to which any single factor affects the stress relaxation of the high-copper amalgams cannot be ascertained. It would appear, however, that the viscoelastic behavior of each alloy is a manifestation of the interaction of unique compositional, metallurgical and physical features.

It is common practice to study the rheological properties of dental amalgam at or near normal mouth temperature (37C). However, in function an amalgam restoration is subjected not only to a broad range of temperatures but also to rapid cyclic temperature change. The materials considered in the present study exhibit differences with respect to the effect of temperature on relaxation behavior. The recent findings suggest that among the alloys, subtle differences in clinical performance potential may exist.

Summary

Stress relaxation of seven high-copper dental amalgam alloys was studied over the temperature range of 0 to 55C. At each test temperature the alloy containing the most copper (30 percent) exhibited the lowest rate and lowest magnitude of stress loss.

Stress losses and relaxation rates of all materials increased with temperature. However, patterns of stress decay could be correlated with neither the compositional nor the structural characteristics of the individual alloys.

Stress relaxation behavior may be an indicator of the relative performance capabilities of high-copper amalgams.

Legends for Figures

Figure 1. Typical fractional stress-loss curves. Experimental
temperature was 37C.   (A) D_t/S_o versus time; and (B) D_t/S_o
versus ln (time + 1).

Figure 2. Relative relaxation rates of seven high copper amalgam alloys.
Curves are best-fit approximations.

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TABLE 1

STRESS-LOSSES AT 60 SECONDS ($D_t/S_o/60$) FOR

HIGH-COPPER AMALGAM ALLOYS

Alloy	Temperature, C							
	0	10	20	30	37	43	48	55
	%	%	%	%	%	%	%	%
A	5(1)*	7(1)*	10(1)*	10(2)*	12(4)*	13(2)*	15(3)*	21(2)*
B	6(2)	9(3)	13(3)	15(5)	20(2)	23(2)	34(2)	34(3)
C	8(2)	10(2)	13(2)	17(3)	19(3)	28(2)	37(6)	44(5)
D	6(1)	7(1)	9(4)	13(1)	13(1)	16(2)	24(2)	34(3)
E	10(1)	13(2)	17(1)	26(2)	36(4)	42(3)	46(4)	56(3)
F	9(2)	11(3)	18(1)	20(1)	28(1)	26(3)	34(4)	31(5)
G	7(2)	11(2)	12(2)	15(1)	17(3)	24(3)	26(3)	30(3)

* Standard deviation in parentheses.

Appendix

HIGH-COPPER AMALGAM ALLOYS: PORTIONING AND TRITURATION

Alloy	Mercury-Alloy Portions mg Hg : mg Alloy			Trituration Time seconds
A[*]	286	:	350	25
B (pellet)	325	:	396	15
C[*]	388	:	388	20
D[*]	315	:	375	15
E (pellet)	459	:	390	20
F[*]	710	:	710	17
G (powder)	700	:	700	17

[*] Precapsulated mercury and alloy.

DT/SO AT 37°C

TIME, SECONDS

ln (TIME+1)

Rate of Stress Relaxation, unit/unit ln Time

TEMPERATURE, C